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APPLICATION OF SUBSYSTEM SUMMARY ALGORITHMS FOR HIGH POWER SYSTEM STUDIES

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Abstract

This paper describes the application of subsystem summary algorithms for self-contained power system configuration trade-off studies, and presents the results of a recently completed study. The development of summary weight algorithms for rocket turbines and rotating electrical generators is described. These new algorithms are combined with previously developed power conditioning subsystem algorithms in a computer program to automatically study various system configurations. A flow chart of the computer program is included in the paper. The computer program was used to find a minimum weight self-contained power system. Results of the study are presented in this paper.

Introduction

Computer aided design has long been recognized as a cost effective technique for determining optional designs of components and subsystems. The Air Force Aero Propulsion Laboratory is committed to developing computer aided design techniques for the optimized design of complete self contained power systems. A three step concept has been adopted: determination of system feasibility, detailed component design, and dynamic system simulation.

System feasibility is determined by the use of summary algorithms representing each component of the system. These algorithms relate each component's weight and volume to the operating parameters that most affect each. The operating parameters are iterated through rather broad ranges until a combination of components meeting the desired system requirements is found. After a combination has been found, the operating parameters of that combination are converted to component design specifications.

The component design specifications are automatically fed to detailed component design computer programs. These programs generate enough detail to completely specify the design of components such as generators, transformers, turbines, and rectifiers. The cooling requirements of each component are specified, but the total cooling system is designed as part of a dynamic simulation package. The final step in the component design process is calculation of the matrix coefficients required for the dynamic simulation.

The matrix coefficients are automatically fed to dynamic simulation programs which fully simulate the electrical and thermal performance of the interconnected components. A main emphasis of the electrical simulation is voltage and current transients. There is also a capability to adjust control philosophies in an attempt to minimize transients. Data from the thermal simulation is retained as an operating profile from which the cooling system is designed.

This paper discusses the summary algorithms used to determine system feasibility. Algorithm development is described. A computer program that combines the algorithms and calculates system weight is discussed, and the results of a sample system study are presented.

Algorithm Development

A summary algorithm describes the weight or volume of a component as a function of those operating, or design, parameters that affect the weight or

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volume. Examples of parameters that affect weight and volume are power level, voltage, and frequency. Each algorithm is normally valid for only a narrow range of parameter values, otherwise accuracy is sacrificed.

Data used to develop the summary algorithms is generated from the detailed design computer programs. The design programs are used to produce numerous designs within the parameter ranges of interest. The data from these designs is organized such that standard curve fitting techniques can be used to form the algorithms. Algorithms developed to date use simple logarithmic curves; however, techniques for using higher order polynomial curve fitting are being implemented.

Two examples of summary algorithms are listed here for completeness. The first was derived from 65 detailed turbine system designs using a mixture of liquid oxygen and liquid hydrogen as the fuel. This algorithm includes tankage, gas generator, pumps, gearboxes, and the turbine.

$$\text{TURBINE SYS WEIGHT} = 6991\,[.262 + .738\,(\frac{HP}{5000})] \times [1.5 - .5\,(\frac{RPM}{12000})^{.556}] \times [.265 + .735\,(\frac{T}{1000})] \times [.9824 + .0176\,(\frac{NS}{10})]\ \text{LBS.}$$

Where: HP = turbine shaft horsepower
RPM = turbine shaft speed
T = total run time (Sec.)
NS = number of starts during T

The second algorithm is for the specific weight of conventional round rotor alternators. This algorithm was derived from 77 detailed designs.

$$\text{LBS/KW} = .157\,[1.28 - .28\,(\frac{P}{5})^{.449}] \times [-.06 + 1.06\,(\frac{RPM}{14000})^{-.6205}] \times [.8567 + .1433\,(\frac{V}{3})]$$

Where: P = power output (MW)
RPM = rotor speed
V = terminal voltage (KV_{L-L})

Development of Computer Program

A computer program that automatically arranges the summary algorithms into possible system configurations was developed for the study reported in this paper. Of particular importance in a study such as this is the propagation of inefficiencies through the system. The program must recognize that the input power demanded by a component is that component's output power plus the power lost to inefficiencies within the component. Figure 1 is a flow chart of the computer program as it presently exists.

Results of System Study

A study was made to find the lightest system configuration that satisfies the following conditions:

Main Power - 5 MW electrical
Aux. Power - .5 MW electrical
Voltage - 100 KVDC - 160 KVDC
Run Time - 500 sec. - 1500 sec.

The three power sources considered were fuel cells, turbine with conventional alternator, and turbine with permanent magnet alternator. Power conditioning components considered included trans formers, rectifiers, and inverters. Figures 2 and 3 depict the possible systems configurations that meet the requirements. There are nine possible combinations of components, as listed in Table 1.

The object of the study was to find the lightest weight system from those of Table 1. Since the computer must use efficiencies, the following efficiencies were assumed:

Filters	- 99.9%
Rectifiers	- 95%
Transformers	- 97%
Inverters	- 85%
Alternators	- 95%

The power levels and voltage ranges are fixed; therefore, the variables include turbine alternator speeds and inverter frequencies. Figures 4 thru 7 show results of the study. The minimum weight system, from Figure 5, is a turbine driven permanent magnet alternator with transformer/rectifier power conditioners in both power channels. The alternator frequency is 2.2 KHZ. Figure 6 indicates that a 100% variation of the inverter frequency causes less than 100 pounds difference in the weights of systems 7, 8, and 9. Figure 7 indicates negligible impact on system weight for

60KV change in the output voltage.

TABLE 1

SYSTEM CONFIGURATIONS

SYSTEM	SOURCE	MAIN CHANNEL	AUX. CHANNEL
1	Con. Alt.	Trans.-Rect.	Trans.-Rect.
2	PM Alt.	Trans.-Rect.	Trans.-Rect.
3	Conv Alt.	Trans.-Rect.	Inverter
4	PM Alt.	Trans.-Rect.	Inverter
5	Conv Alt.	Inverter	Trans.-Rect.
6	PM Alt.	Inverter	Trans.-Rect.
7	Conv Alt.	Inverter	Inverter
8	PM Alt.	Inverter	Inverter
9	Fuel Cell	Inverter	Inverter

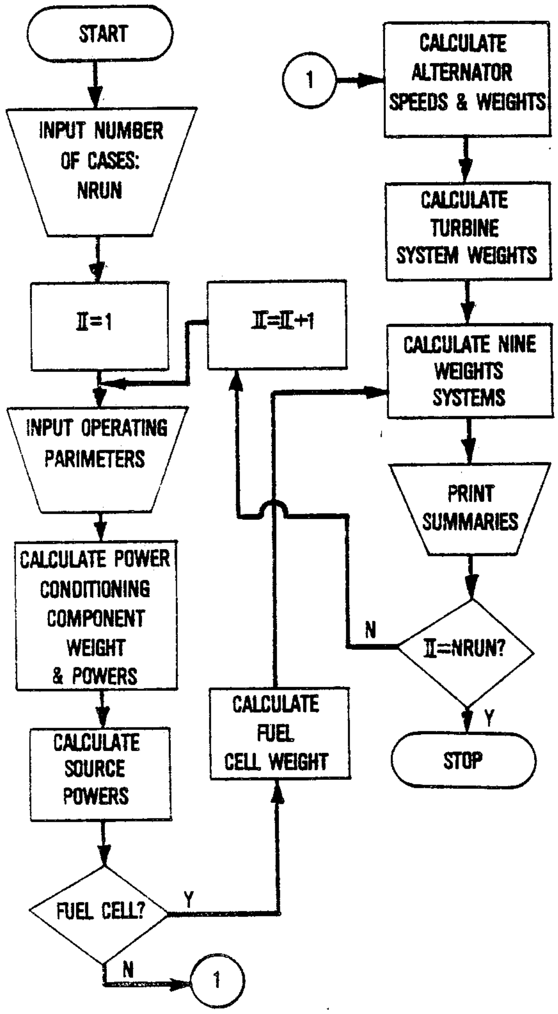

Fig. 1 Flow Chart of Prog. to Cal. Sys. Weights

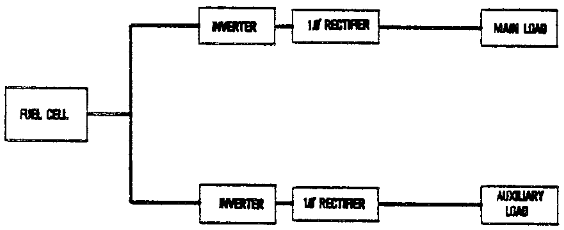

Fig. 2 System Using Fuel Cell Source

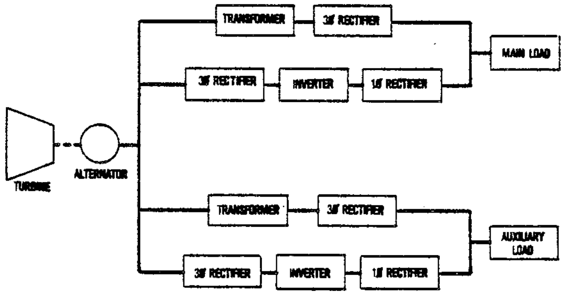

Fig. 3 Systems Using Turbine/Alternator Sources

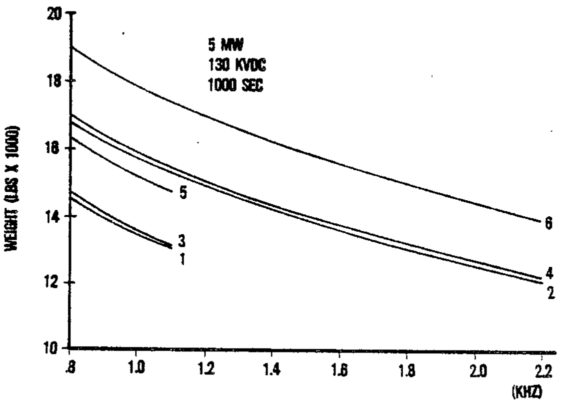

Fig. 4 System Weights as a Function of Atlernator Frequency

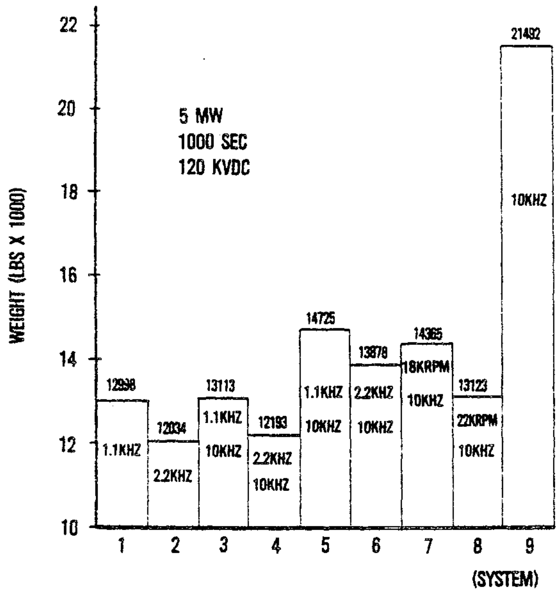

Fig. 5 Minimum Weight Systems

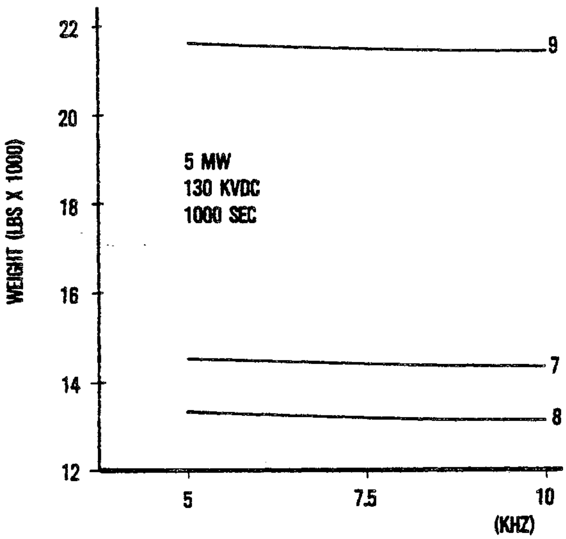

Fig. 6 System Weights as a Function of Inverter Frequency

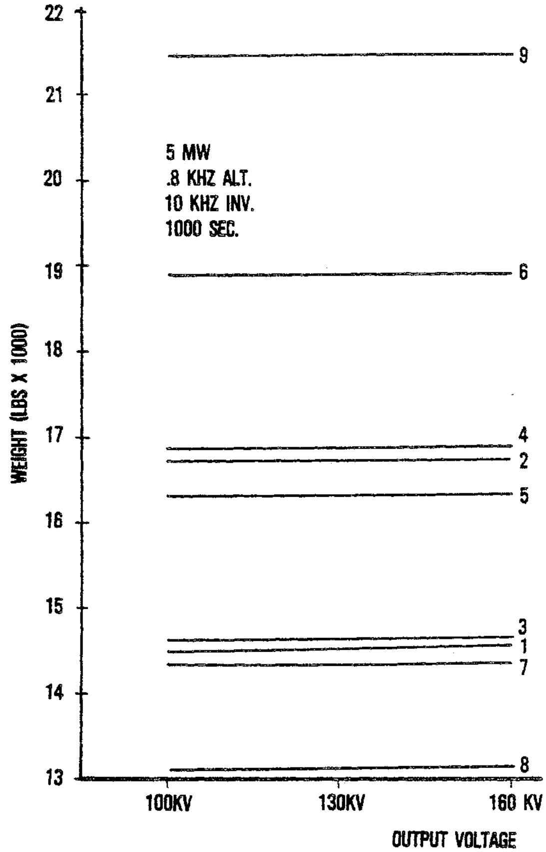

Fig. 7 System Weight as a Function of Output Voltage